Coastal Engineering Technical Note

Estimating Scour Caused by Deflected Ebb Flows

By Steven A. Hughes

PURPOSE

To estimate maximum scour potential when tidal ebb flow is deflected by an inlet navigation jetty.

PROBLEM

Scour hole formation adjacent to the channel-side toe of protective inlet jetty structures is a troublesome problem at some navigation inlets. Without remedial action, continued scour hole growth may result in jetty instability and partial collapse of the structure. In addition, deep scouring adjacent to the channel side of a protective jetty may be accompanied by shoaling of the maintained navigation channel, shifting the de facto navigation channel dangerously close to the jetty.

DEFLECTED EBB FLOW SCOUR

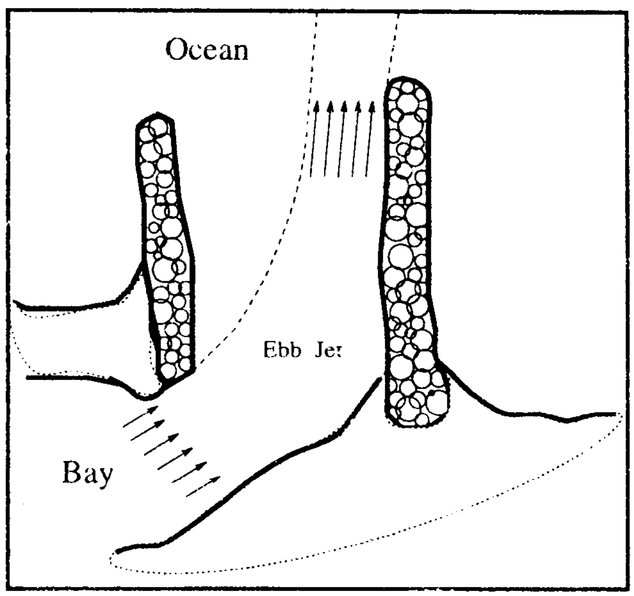

Figure 1. Ebb flow deflection

From a survey of scour problems experienced at inlets (Lillycrop and Hughes 1993), it appears that one of the more important physical mechanisms causing scour at inlets during the ebb flow tidal cycle is strong ebb currents that exit the inner bay and impinge on the structure at an angle, as shown schematically by Figure 1. Laboratory observations indicated that as the ebb flow is deflected, the width of the flow parallel to the navigation structure is reduced, much like the deflection of a water jet. This results in increased flow velocity adjacent to the jetty in order to maintain the same flow discharge over the reduced cross section. Over many ebb-tidal cycles, the increased velocities scour the bottom and enlarge the flow cross-sectional area until eventually flow velocities are reduced to non-scouring levels. The scour process is further complicated by the influence of short-period

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14. ABSTRACT
This Coastal Engineering Technical Note (CETN) demonstrates how to estimate maximum scour potential when ebb flow is deflected by an inlet navigation jetty.

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waves in the channel, entrainment at the flow shear interface, changes in flow velocity over the ebb cycle, and the influence of a porous jetty structure.

Remedial actions to protect the jetty may involve infilling the scour hole and protecting the bottom with a stone apron. Repairs which effectively reduce the ebb flow cross-sectional area are likely to produce increased flow velocities, which may impact inlet navigation.

ESTIMATION METHODOLOGY

The physical process of ebb flow deflection by a structure can be approximated as an inviscid free jet exiting the ebb channel and impinging on the structure. This approximation assumes that the flow distribution is uniform over the cross section of the flow *"jet."* In other words, boundary layer effects are neglected, and no flow entrainment occurs between the *"ebb jet"* and adjacent still water (as represented by the dashed line in Figure 1). Using the notation and coordinate system shown in Figure 2, an inviscid, potential flow solution was specified that links the flow field to the geometry of the solid boundaries (Hughes and Kamphuis 1996). This solution resulted in implicit equations that cannot be solved directly. However, the solution can be represented in design nomograms for a specified jet deflection angle θ.

Figures 3-5 present nomograms generated for ebb-flow deflection angles of 30°, 45°, and 60° ($\kappa\pi = \pi/6$, $\pi/4$, and $\pi/3$, respectively). The solid lines on the nomograms are contours of equal values for l/L and the dashed lines represent constant values of b/L. For a given inlet geometry, the unique solution is found at the intersection of the appropriate values of l/L and b/L. At this intersection point, the *"velocity function"* h is read on the vertical axis. The unknown velocity V_o corresponding to an entrance channel value of V_m can be determined from the expression

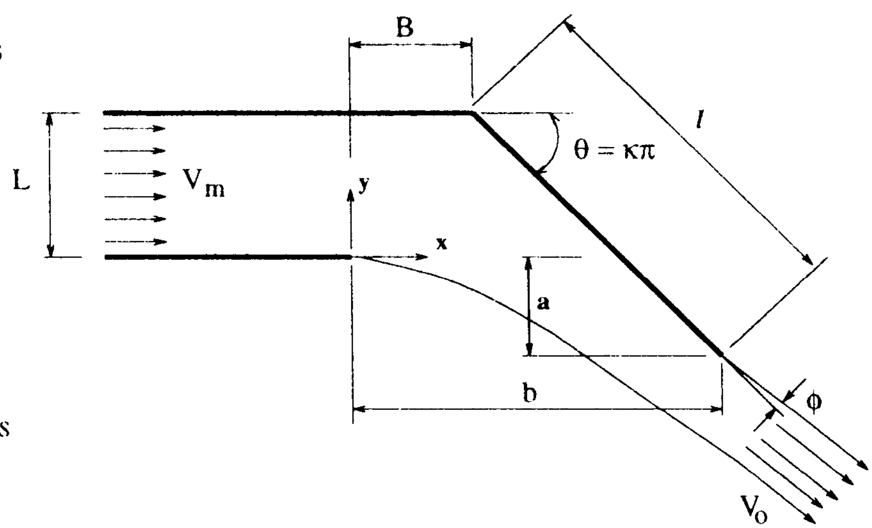

Figure 2. Ebb-Jet coordinate system

$$\frac{V_m}{V_o} = h^{\kappa} \qquad or \qquad V_o = \frac{V_m}{h^{\kappa}} \tag{1}$$

where κ is the fraction associated with the deflection angle $\kappa\pi$. The jet exit angle given on the nomogram abscissa is not used in this estimation methodology.

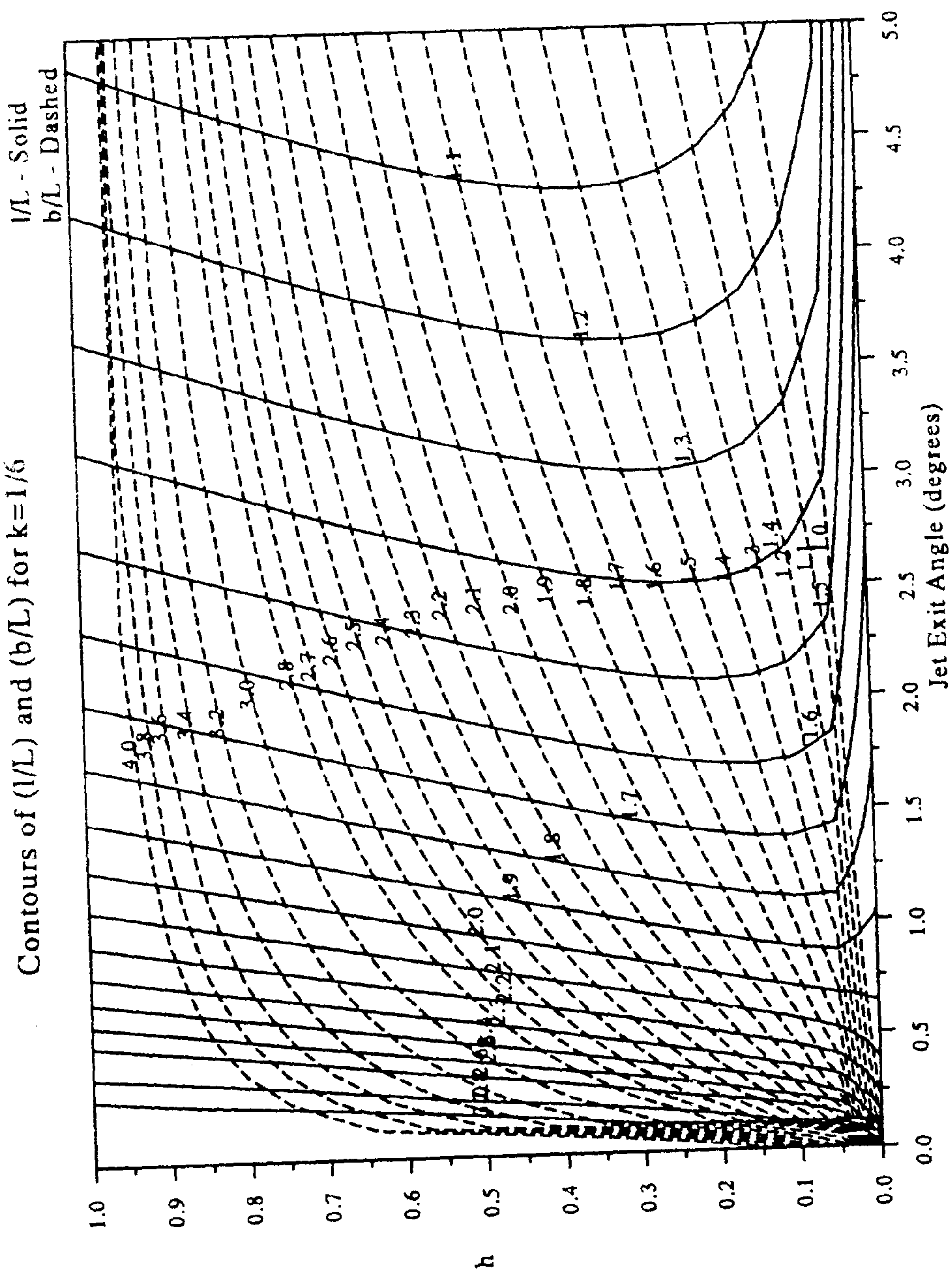

Figure 3. Velocity nomogram for ebb flow deflection angle of 30° (κ = 1/6)

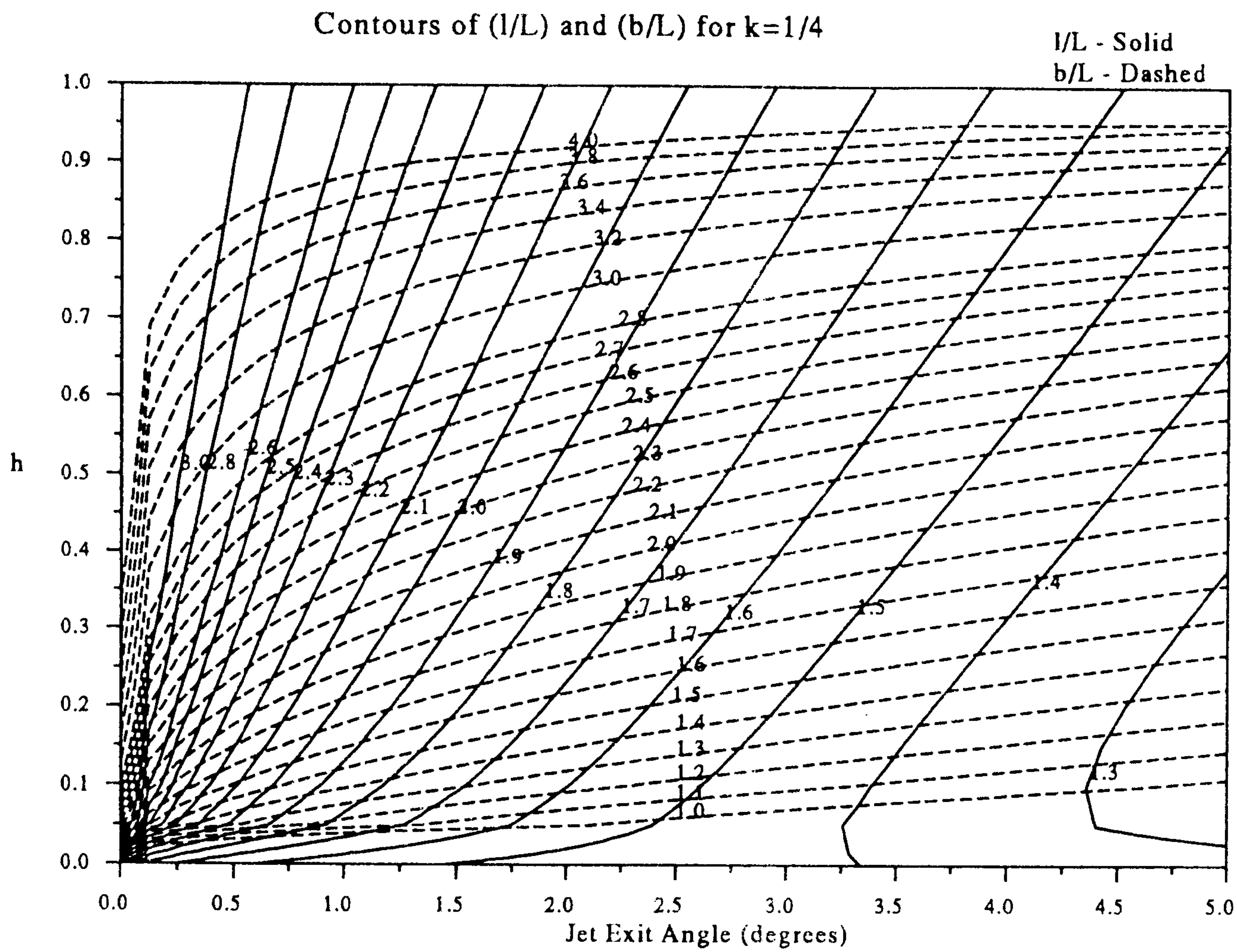

Figure 4. Velocity nomogram for ebb flow deflection angle of 45° ($\kappa = 1/4$)

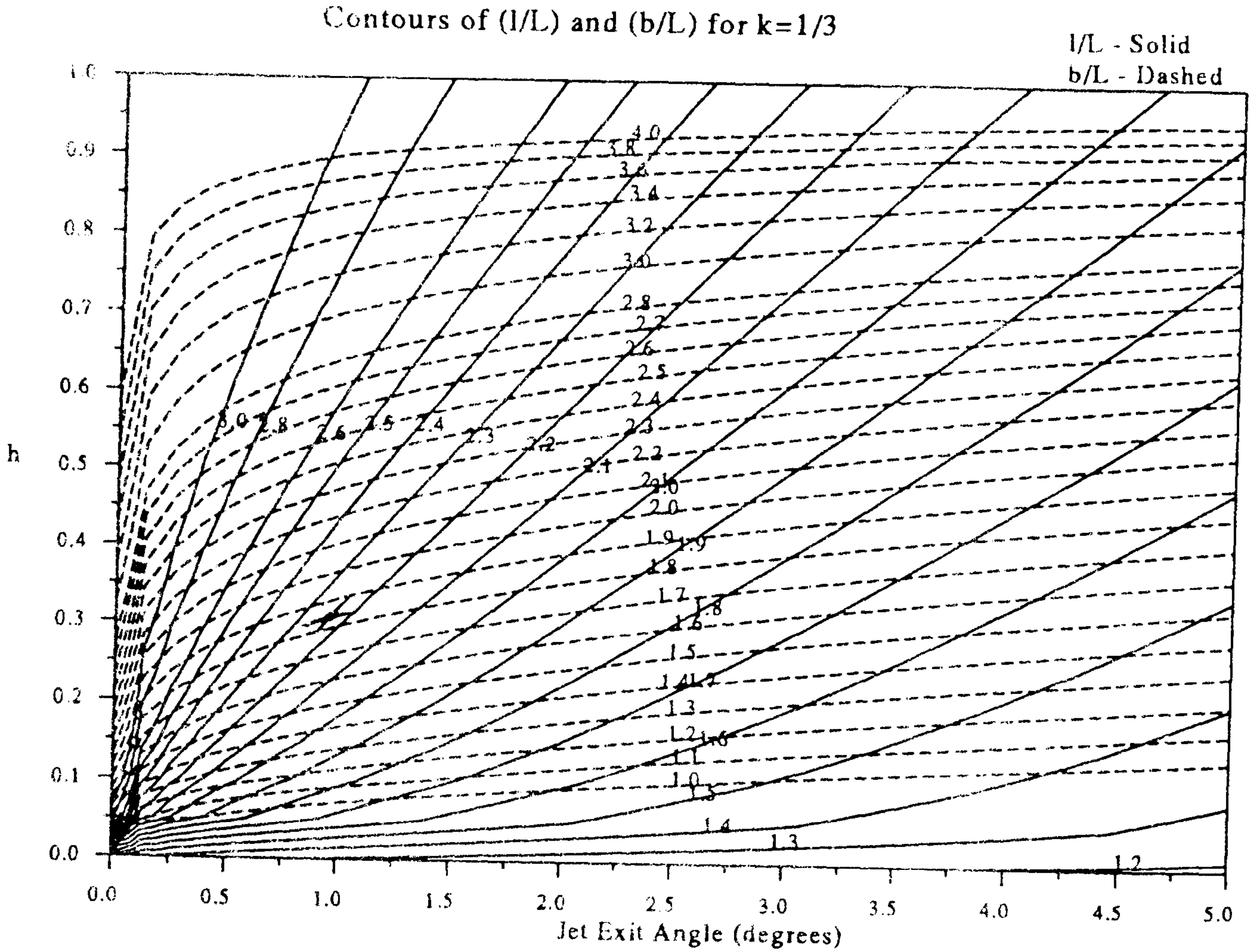

Figure 5. Velocity nomogram for ebb flow deflection angle of 60° (κ = 1/3)

The velocity estimate of V_o found using Equation 1 assumes a flat bottom of constant depth, i.e., the depth adjacent to the structure is the same as the depth in the entrance channel where the velocity is V_m. Consequently, the estimated value of V_o represents the maximum velocity that could occur.

SCOUR ESTIMATES

From simple flow continuity the total discharge at the entrance channel must be equal to the total discharge at the point adjacent to the structure where the flow width is minimum, or $Q_m = Q_o$. Discharge is the mean velocity times the cross sectional area; and assuming rectangular flow cross sections, flow continuity can be expressed as

$$(d_m L)V_m = (d_o w_o)V_o \qquad or \qquad \left(\frac{V_m}{V_o}\right)\left(\frac{L}{w_o}\right)\left(\frac{d_m}{d_o}\right) = 1 \tag{2}$$

where d is the depth at the location denoted by the subscript; L is the width of the entrance channel (see Figure 2); and w_o is the narrowest width of the ebb jet. On a constant depth bottom $d_m = d_o$, and Equation 2 becomes

$$\frac{w_o}{L} = h^{\kappa} \tag{3}$$

when the velocity ratio is substituted from Equation 1. Under the assumption that jet width remains constant if erosion occurs at d_o, Equation 3 can be substituted into Equation 2 to give the following continuity relationship for deflected ebb jets

$$\left(\frac{V_m}{V_o}\right)\left(\frac{1}{h^{\kappa}}\right)\left(\frac{d_m}{d_o}\right) = 1 \tag{4}$$

Assuming the velocity V_m in the entrance channel is just at the sediment incipient motion threshold (and the jet width remains constant), it is hypothesized that the seabed at the narrowest part of the ebb jet will erode until the velocity at that location reduces from V_o to V_m. The depth of scour necessary to maintain the flow discharge is found from Equation 4 with $V_o = V_m$, or

$$d_o = \frac{d_m}{h^{\kappa}} \tag{5}$$

VELOCITY ESTIMATES

If deflected ebb-flow scour threatens the structural integrity of a navigation jetty, the usual solution is to fill in the scour hole to some depth and then protect the repair with a stone apron. In this situation, flow velocities adjacent to the jetty should increase because the flow cross-sectional area is decreased. An estimate of the increased flow velocity is needed to help design the stone apron and to assess potential navigation impacts.

Under the same assumptions stated previously, the deflected ebb jet continuity equation can be used to make crude velocity estimates by simply rearranging Equation 4 into the form

$$V_o = \left(\frac{d_m}{d_o}\right)\left(\frac{\frac{V_m}{h^\kappa}}{V_m}\right) \qquad (6)$$

Because of the assumptions of (1) inviscid flow, (2) uniform velocity distributions, and (3) rectangular inlet cross sections, scour and velocity estimates must be considered crude. Fortunately, comparisons with movable-bed laboratory tests indicate better correspondence close to the jetty where scour is more likely to cause structure damage. Also note that this method assumes scour next to the jetty is caused solely by the ebb currents. Impacts of waves, wave reflection, and wave/current interactions are neglected.

-- Example Problem --

EXAMPLE APPLICATION

Figure 6 is a sketch of Ponce de Leon Inlet, Florida, showing depth-averaged velocity vectors acquired about the time of peak ebb flow. Also shown on the figure are the geometry variables used in the simple scour prediction method described in this note. The maximum depth at the ebb-channel entrance cross section was about 24 ft, and the maximum scour adjacent to the structure was around 38-40 ft (from 1994 *SHOALS* survey).

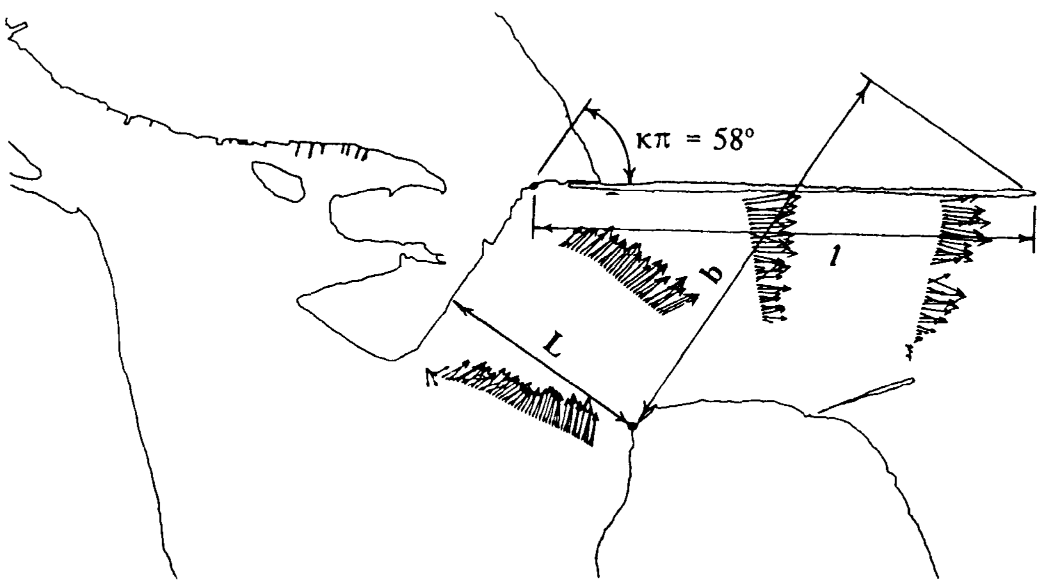

Figure 6. Ponce de Leon Inlet example

The deflection angle is approximately 60° ($\pi/3$ in radians), so the angle parameter is $\kappa = 1/3$. Scaling the lengths from Figure 6 yields the dimensionless ratios

$$\frac{l}{L} = 2.24 \qquad and \qquad \frac{b}{L} = 1.84$$

Using these values for l/L and b/L with the nomogram for $\kappa = 1/3$ (indicated by mark on Figure 5) gives a velocity factor of

$$h = 0.31$$

(Note: For deflection angles other than those given in Figures 3-5, calculate for angles given by the nomograms and interpolate between the values to find a value for h. Custom nomograms for any angle can be generated on request.)

Maximum Scour: Maximum deflected ebb-flow scour adjacent to the jetty is estimated using Equation 5 with $d_m = 24$ ft, i.e.,

$$d_o = \frac{24\ ft}{(0.31)^{1/3}} = 35.5\ ft$$

This compares favorably with the actual maximum scour at Ponce de Leon Inlet, but this agreement may be fortuitous and should not be considered validation of this simple technique.

Velocity Adjacent to Jetty: If the scour hole were to be infilled to a depth of 30 ft, an estimate of peak ebb-flow velocity increase can be obtained using Equation 6

$$V_o = \left(\frac{24\ ft}{30\ ft}\right)\frac{V_m}{(0.31)^{1/3}} = 1.18\ V_m$$

This result implies that maximum ebb-flow velocities adjacent to the jetty would increase to a value that is 18 percent greater than the maximum flow at the ebb channel entrance. (Recall that at maximum scour depth, it is assumed that $V_o = V_m$.)

FUTURE DEVELOPMENTS

Future efforts will extend and refine this preliminary design tool by introducing empirical relationships to approximate bottom boundary layers and the effects of turbulent flow entrainment at the "ebb jet" shear boundary. Allowing for nonuniform entrance channel bathymetry and velocity distributions will require numerical model development. Validation at other inlets is planned after the enhanced scour prediction method has been developed.

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ADDITIONAL INFORMATION

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